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Title:

Nickel based alloys resistant to sulphidation and oxidation.

Abstract:

A nickel-base alloy is disclosed containing (in weight percent) Chromium 25-35
Aluminium 2-5 Iron 2.5-6 Niobium 0-2.5 Carbon 0-0.1 Nitrogen 0-0.05 Titanium 0-1
Zirconium 0-1 Boron 0-0.01 Cerium 0-0.05 Yttrium 0-0.05 Silicon 0-1 Manganese 0-1 Nickel
Rest The alloy affords a high degree of resistance to sulphidation and oxidation at
elevated temperatures and is suitable for use in glass vitrification furnaces.



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60 Nickel based alloys resistant to sulphidation and oxidation.

67 A nickel-base alloy is disclosed containing (in weight percent)

| | |
|-----------|--------|
| Chromium | 25-35 |
| Aluminium | 2-5 |
| Iron | 2.5-6 |
| Niobium | 0-2.5 |
| Carbon | 0-0.1 |
| Nitrogen | 0-0.05 |
| Titanium | 0-1 |
| Zirconium | 0-1 |
| Boron | 0-0.01 |
| Cerium | 0-0.05 |
| Yttrium | 0-0.05 |
| Silicon | 0-1 |
| Manganese | 0-1 |
| Nickel | Rest |

The alloy affords a high degree of resistance to sulphidation and oxidation at elevated temperatures and is suitable for use in glass vitrification furnaces.

EP 0 338 574 A1

Alloys resistant to sulphidation and oxidation.

The present invention is directed to nickel-chromium alloys, and more particularly to nickel-chromium alloys which offer a high degree of resistance to sulphidation and oxidation attack at elevated temperatures together with good stress rupture and tensile strengths and other desired properties.

Nickel-chromium alloys are known for their capability of affording various degrees of resistance to a host of diverse corrosive environments. For this reason such alloys have been widely used in sundry applications, from superalloys in aerospace to marine environments. One particular area of utility has been in glass vitrification furnaces for nuclear wastes. The alloy that has been conventionally employed is a nominal 60 Ni - 30 Cr - 10 Fe composition which is used as the electrode material submerged in the molten glass and for the pouring spout. It has also been used for the heaters mounted in the roof of the furnace and for the effluent containment hardware.

By reason of its strength and corrosion resistance in such an environment, the 60 Ni - 30 Cr - 10 Fe alloy provides satisfactory service for a period of circa 2 years, sometimes less, sometimes more. It normally fails by way of sulphidation and/or oxidation attack, probably both. It would thus be desirable if an alloy for such an intended purpose were capable of offering an extended service life, say 3 to 5 years or more. This would not only require a material of greatly improved sulphidation/oxidation resistance, but also a material that possessed high stress rupture strength characteristics at such operating temperatures, and also good tensile strength, toughness and ductility, the latter being important in terms of formability operations. To attain the desired corrosion characteristics at the expense of strength and other properties would not be a desired panacea.

We have found that an alloy containing controlled and correlated percentages of nickel, chromium, aluminium, iron, carbon and preferably also niobium, as further described herein, provides an excellent combination of

- (i) sulphidation and
- (ii) oxidation resistance at elevated temperatures, e.g. 982-1093 °C
- (iii) together with good stress rupture and creep strength at such high temperatures; plus
- (iv) satisfactory tensile strength,
- (v) toughness,
- (vi) ductility, etc.

As an added attribute, the alloy is also resistant to carburisation. In terms of a glass vitrification furnace, the subject alloy is deemed highly suitable to resist the ravages occasioned by corrosive attack above the glass phase. In this zone of the furnace the alloy material is exposed to and comes into contact with a complex corrosive vapour containing such constituents as nitrogen oxide, nitrates, carbon dioxide, carbon monoxide, mercury and splattered molten glass and glass vapours.

Apart from combatting such an aggressive environment an improved alloy must be capable of resisting stress rupture failure at the operating temperature of the said zone. This, in accordance herewith, requires an alloy which is characterised by a stress rupture life of about 200 hours or more under a stress of 13.7 MPa and a temperature of 980 °C.

Generally speaking, the present invention contemplates a nickel-base, high chromium alloy characterised by good sulphidation and oxidation resistance together with a good stress rupture life and ductility at elevated temperature and good room temperature tensile and ductility properties, said alloy consisting essentially of 25 to 35% chromium, 2 to 5% aluminium, about 2.5 to 6% iron, up to 2.5% niobium, up to 0.1% carbon, up to about 0.05% nitrogen, up to 1% titanium, up to 1% zirconium, up to 0.01% boron, up to 0.05% cerium, up to 0.05% yttrium, up to 1% silicon, up to 1% manganese, and the balance nickel. All percentages in alloy compositions herein are by weight. The alloy may for example contain 2.5 to 4% aluminium, 2.5 to 5.5% iron, 0.75 to 1.5% niobium, up to 0.05% carbon, up to 0.012% cerium, up to 0.5% titanium and up to 0.5% zirconium.

An embodiment of the invention contemplates a nickel-base, high-chromium alloy which contains about 27 to 35% chromium, from about 2.5 to 5% aluminium, about 2.5 to 5.5 or 6% iron, from 0.0001 to about 0.1% carbon, from 0.5 to 2.5% niobium, up to 1% titanium, up to 1% zirconium, up to about 0.05% cerium, up to about 0.05% yttrium, up to 0.01% boron, up to 1% silicon, up to 1% manganese, the balance being essentially nickel. The term "balance" or "balance essentially" as used herein does not, unless indicated to the contrary, exclude the presence of other elements which do not adversely affect the basic characteristics of the alloy, including incidental elements used for cleansing and deoxidising purposes. Phosphorus and sulphur should be maintained at the lowest levels consistent with good melting practice. Nitrogen is beneficially present up to about 0.04 or 0.05%.

In carrying the invention into practice it is preferred that the chromium content not exceed about 32%, this by reason that higher levels tend to cause spalling or scaling in oxidative environments and detract from stress rupture ductility. The chromium can be extended down to, say, 25% but at the risk of loss in corrosion resistance, particularly in respect of the more aggressive corrosives.

- Aluminium markedly improves sulphidation resistance and also resistance to oxidation. It is most preferred that it be present in amounts of at least about 2.75 or 3%. High levels detract from toughness in the aged condition. An upper level of about 3.5 or 4% is preferred. As is the case with chromium, aluminium percentages down to 2% can be employed but again at a sacrifice of corrosion resistance. Iron if present much in excess of 5.5 or 6% can introduce unnecessary problems. It is theorised that iron segregates at the grain boundaries such that carbide morphology is adversely affected and corrosion resistance is impaired. Advantageously, iron should not exceed 5%. It does tend to the use of ferrochrome; thus, there is an economic benefit. A range of 2.75 to 5% is deemed most satisfactory.

- As above indicated, it is preferred that the alloys contain niobium and in this regard at least 0.5 and advantageously at least 1% should be present. It advantageously does not exceed 1.5%. Niobium contributes to oxidation resistance. However, if used to excess, particularly in combination with the higher chromium and aluminium levels, morphological problems may ensue and rupture-life and ductility can be affected. In the less aggressive environments niobium may be omitted but poorer results can be expected. Titanium and zirconium provide strengthening and zirconium adds to scale adhesion. However, titanium detracts from oxidation resistance and it is preferred that it not exceed about 0.5%, preferably 0.3%. Zirconium need not exceed 0.5%, e.g. 0.25%. It is preferred that carbon not exceed about 0.04 or 0.05%. Boron is useful as a deoxidiser and from 0.001 to 0.01% can be utilised to advantage. Cerium and yttrium, particularly the former, impart resistance to oxidation. A cerium range of about 0.005 or 0.008 to 0.015 or 0.012% is deemed quite satisfactory. Yttrium need not exceed 0.01%.

- Manganese subverts oxidation resistance and it is preferred that it not exceed about 0.5%, and is preferably held to 0.2% or less. A silicon range of 0.05 to 0.5% is satisfactory.

- In respect of processing procedures vacuum melting is recommended. Electroslag remelting can also be used but it is more difficult to hold nitrogen using such processing. Hot working can be conducted over the range of 982° to 1150° C. Annealing treatments should be performed within the temperature range of about 1038 to 1204° C, e.g. 1065 to 1177° C, for up to 2 hours, depending upon section size. One hour is usually sufficient. The alloy primarily is not intended to be used in the age-hardened condition. However, for applications requiring the highest stress rupture strength levels at, say, intermediate temperatures of 650 to 927 or 982° C the instant alloy can be aged at 704 to 815° C for up to, say, 4 hours. Conventional double ageing treatments may also be utilised. It should be noted that at the high sulphidation/oxidation temperatures contemplated, e.g. 1093° C, the precipitating phase (Ni₃Al) formed upon age hardening would go back into solution. Thus, there would be no beneficial effect by ageing though there would be at the intermediate temperatures.

For the purpose of giving those skilled in the art a better appreciation of the invention, the following illustrative data are given.

- A series of 15 kg heats was prepared using vacuum melting, the compositions being given in TABLE I below. Alloys A to F, outside the invention, were hot-forged at 1175° C for 102 mm diameter x length ingots to 20.4 mm diameter x length rod. A final anneal at 1040° C for 1 hour followed by air cooling was utilised. Oxidation pins 7.65 mm in diameter by 19.1 mm in length were machined and cleaned in acetone. The pins were exposed for 240 hours at 1100° C in air plus 5% water atmosphere using an electrically heated mullite tube furnace. Oxidation data are graphically shown in Fig. 1. Alloys A to F are deemed representative of the conventional 60 Ni - 30 Cr - 10 Fe alloy with small additions of cerium, niobium and aluminium. The nominal 60 Ni - 30 Cr - 10 Fe alloy normally contains small percentages of titanium, silicon, manganese and carbon. Oxidation results for standard 60 Ni - 30 Cr - 10 Fe are included in TABLE IIA and Fig. 1.

- Alloys 1 to 16, G, H and I, also set forth in TABLE I, were vacuum-cast as above but were hot-rolled to final bar size at 1120° C rather than having been initially hot-forged. Sulphidation and oxidation results are reported in TABLES II and IIA. Carburisation-resistance results are given in TABLE IIB under the test conditions given therein. Stress rupture properties are given in TABLE III with tensile properties being set forth in TABLE IV. Figs. 2 and 3 also graphically depict oxidation results of Alloys 1, 10 and 11. Figs. 4 and 5 illustrate graphically the sulphidation results for Alloys 1, 2 and 3 (Fig. 4) and Alloys 4 to 9 (Fig. 5). The oxidation test was the cyclic type wherein specimens were charged in an electrically heated tube furnace for 24 hours. Samples were then weighed. The cycle was repeated for 42 days (unless otherwise indicated). Air plus 5% water vapour was the medium used for the test. The sulphidation test consisted of metering the

test medium ($H_2 + 45\% CO_2 + 1\% H_2S$) into an electric heater tube furnace (capped ends). Specimens were approximately 7.5 mm diameter x 19 mm high and were contained in a cordierite boat. Time periods are given in TABLE II.

TABLE I

| Composition Weight Per Cent | | | | | | | | | |
|-----------------------------|-------|-------|------|-------|------|-------|-------|-------|--------|
| Alloy | C | Mn | Fe | Cr | Al | Nb | Si | Ti | Ce |
| A | 0.16 | 0.180 | 8.84 | 29.22 | 0.32 | 0.06 | 0.11 | 0.37 | 0.0005 |
| B | 0.053 | 0.160 | 8.50 | 29.93 | 0.31 | 0.02 | 0.25 | 0.37 | 0.021 |
| C | 0.051 | 0.160 | 7.59 | 30.04 | 0.33 | 0.99 | 0.28 | 0.36 | 0.0005 |
| D | 0.032 | 0.160 | 7.71 | 30.06 | 0.31 | 0.10 | 0.28 | 1.02 | 0.0005 |
| E | 0.027 | 0.160 | 7.48 | 30.05 | 0.32 | 0.99 | 0.27 | 0.40 | 0.018 |
| F | 0.039 | 0.020 | 8.54 | 30.33 | 0.30 | 0.11 | 0.26 | 0.36 | 0.012 |
| G | 0.006 | 0.010 | 7.00 | 29.49 | 2.75 | 0.57 | 0.130 | 0.02 | 0.011 |
| 1 | 0.007 | 0.010 | 5.95 | 29.89 | 2.85 | 1.07 | 0.130 | 0.02 | 0.005 |
| 2 | 0.006 | 0.010 | 5.80 | 30.01 | 3.27 | 0.54 | 0.120 | 0.01 | 0.016 |
| 3 | 0.009 | 0.010 | 4.30 | 30.02 | 3.27 | 2.04 | 0.140 | 0.02 | 0.016 |
| H | 0.009 | 0.010 | 9.04 | 29.95 | 0.41 | 0.17 | 0.140 | 0.01 | 0.001 |
| 4 | 0.002 | 0.081 | 4.45 | 31.90 | 3.11 | 1.05 | 0.370 | 0.22 | 0.004* |
| 5 | 0.007 | 0.099 | 4.53 | 34.94 | 3.20 | 1.07 | 0.380 | 0.22 | 0.005* |
| 6 | 0.006 | 0.100 | 3.81 | 30.45 | 3.99 | 1.06 | 0.380 | 0.22 | 0.004* |
| 7 | 0.006 | 0.100 | 2.79 | 30.20 | 3.98 | 2.00 | 0.370 | 0.22 | 0.004* |
| 8 | 0.007 | 0.110 | 4.63 | 30.00 | 3.08 | 1.13 | 0.380 | 0.23 | 0.037* |
| 9 | 0.006 | 0.098 | 3.75 | 30.14 | 3.05 | 2.01 | 0.380 | 0.21 | 0.044* |
| I | 0.011 | 0.018 | 8.47 | 27.19 | 2.8 | 0.10 | 0.079 | 0.007 | 0.013 |
| 10 | 0.015 | 0.014 | 5.57 | 29.42 | 3.20 | 1.04 | 0.075 | 0.02 | 0.008 |
| 11 | 0.026 | 0.014 | 5.41 | 30.05 | 4.10 | 0.02 | 0.053 | 0.02 | 0.015 |
| 12 | 0.006 | 0.005 | 5.93 | 30.00 | 3.30 | 0.21 | 0.11 | 0.001 | 0.008 |
| 13 | 0.008 | 0.006 | 6.18 | 30.05 | 3.33 | 0.020 | 0.11 | 0.001 | 0.019 |
| 14 | 0.010 | 0.004 | 5.89 | 30.15 | 3.19 | 0.48 | 0.11 | 0.001 | 0.017 |
| 15 | 0.008 | 0.004 | 5.62 | 30.18 | 3.35 | 0.51 | 0.12 | 0.001 | - |
| 16 | 0.012 | 0.003 | 5.45 | 30.19 | 3.37 | 0.51 | 0.10 | 0.001 | 0.0005 |

*Nitrogen, not cerium.

TABLE II

| Sulfidation Resistance | | |
|------------------------|-----------------------|----------|
| Alloy | Mass Gain at 815 °C | |
| | (mg/cm ²) | Time (h) |
| 60Ni-30Cr-10Fe | 101.0 | 48 |
| G | 11.9 | 528 |
| 1 | 45.5 | 408 |
| 2 | 6.6 | 528 |
| 3 | 2.3 | 2232 |
| H | 78.6 | 24 |
| 4 | 8.5 | 1200 |
| 5 | -13.7 | 1200 |
| 6 | 1.4 | 1200 |
| 7 | 1.3 | 1200 |
| 8 | 8.9 | 1200 |
| 9 | 2.8 | 1200 |
| I | 29.0 | 24 |
| 10 | 54.5 | 54 |
| 11 | 0.4 | 1008 |
| 12 | 0.3 | 840 |
| 13 | 1.6 | 840 |
| 14 | 0.6 | 840 |
| 15 | -0.3 | 840 |
| 16 | 0.7 | 840 |

TABLE II A

| 24 Hour Cyclic Oxidation Resistance | | | | | | |
|-------------------------------------|------------------------|----------|-----------------------|----------|-----------------------|----------|
| Alloy | Undescaled Mass Change | | | | | |
| | 1000 °C | | 1100 °C | | 1205 °C | |
| | (mg/cm ²) | Time (h) | (mg/cm ²) | Time (h) | (mg/cm ²) | Time (h) |
| 60-30-10 | 0.3 | 264 | -10.3 | 500 | - | - |
| G | -0.4 | 1008 | -1.5 | 1008 | - | - |
| 1 | -1.2 | 1008 | -0.1 | 1008 | - | - |
| 2 | -0.1 | 1008 | -0.1 | 1008 | - | - |
| 3 | -0.3 | 1008 | -0.2 | 1008 | - | - |
| H | 0.1 | 1008 | -2.0 | 1008 | - | - |
| 4 | 0.9 | 1008 | -6.5 | 1008 | - | - |
| 5 | 0.5 | 1008 | -7.6 | 1008 | - | - |
| 6 | -1.3 | 1008 | -2.9 | 1008 | - | - |
| 7 | -2.0 | 1008 | -4.3 | 1008 | - | - |
| 8 | -0.1 | 1008 | -10.4 | 1008 | - | - |
| 9 | -0.8 | 1008 | -6.3 | 1008 | - | - |
| I | 1.4 | 1032 | -5.7 | 1008 | -33.6 | 984 |
| 10 | 0.2 | 1032 | 0.7 | 1008 | 0.5 | 984 |
| 11 | 0.6 | 1032 | 0.7 | 1008 | -2.1 | 984 |
| 12 | -0.2 | 840 | -0.1 | 840 | - | - |
| 13 | +0.3 | 840 | -3.5 | 840 | - | - |
| 14 | -0.2 | 840 | -1.8 | 840 | - | - |
| 15 | -0.6 | 840 | -2.3 | 840 | - | - |
| 16 | -0.1 | 840 | +0.9 | 840 | - | - |

TABLE IIB

| | Carburization Resistance | | |
|----------|--------------------------|---|---|
| | Alloy | Mass Gain at 1000 °C in 1008 h | |
| | | H ₂ - 1%CH ₄ (mg/cm ²) | H ₂ - 12% CH ₄ - 10% H ₂ O mg/cm ²) |
| 60-30-10 | | 23.7 | 28.9 |
| G | | 9.2 | 10.7 |
| 1 | | 9.6 | 12.0 |
| 2 | | 6.0 | 2.1 |
| 3 | | 2.0 | 1.7 |
| H | | 37.5 | 29.0 |
| 4 | | 10.9 | 20.8 |
| 5 | | 7.9 | 17.9 |
| 6 | | 3.8 | 6.2 |
| 7 | | 5.5 | 4.6 |
| 8 | | 7.5 | 8.4 |
| 9 | | 4.6 | 5.9 |
| I | | 0.5 | 13.7 |
| 10 | | 0.6 | 0.8 |
| 11 | | 1.4 | 0.5 |
| 12 | | 8.5(at 792h) | 5.1 (at 792h) |
| 13 | | 6.3 " | 6.9 " |
| 14 | | 8.1 " | 4.5 " |
| 15 | | 7.6 " | 8.2 " |
| 16 | | 6.4 " | 7.4 " |

TABLE III

| Stress Rupture Properties at 13.7 MPa/980 °C | | |
|--|---------------|---------------------|
| Alloy | Condition | Time to Rupture (h) |
| 60-30-10 | | |
| G | HR + An | 329, 582 |
| G | HR + An + Age | 1064 |
| 1 | HR + An | 210, 276 |
| 1 | HR + An + Age | 289 |
| 2 | HR + An | 1330 |
| 3 | HR + An | 938, 1089 |
| 4 | HR + An | 192, 355 |
| I | HR + An + Age | 1385*, 5636, 5664 |
| 10 | HR + An | 302 |
| 10 | HR + An + Age | 310, 320 |
| 11 | HR + An | 1534* |
| 11 | HR + An + Age | 1389* |

*Duplicate samples were increased to 34.2 MPa at time shown. Failure occurred within 0.1 h in all cases.

HR = hot rolled at 1120 °C

An = annealed at 1040 °C

Age = 700 °C /500 h /Air Cool

TABLE IIIA

| Alloy Alloy | Conditions Conditions | Stress, (MPa) | Temp., (° C) | Time to Rupture (h) | Elong. (%) |
|-----------------------------|-----------------------|---------------|--------------|---------------------|------------|
| 4 | HR + An(1) | - | - | - | - |
| | HR + An(2) | 27.4 | 980 | 41.7 | 27.3 |
| 5 | HR + An(1) | 13.7 | 1093 | 18.0 | 64.1 |
| | HR + An(2) | 13.7 | 1093 | 14.5 | 64.7 |
| 5 | HR + An(1) | 27.4 | 980 | 12.7 | 33.6 |
| | HR + An(2) | 27.4 | 980 | 61.9 | 16.7 |
| 7 | HR + An(1) | 13.7 | 1093 | - | X |
| | HR + An(2) | 13.7 | 1093 | - | X |
| 7 | HR + An(1) | 27.4 | 980 | 6.5 | 12.3 |
| | HR + An(2) | 27.4 | 980 | 66.6 | 62.6 |
| 8 | HR + An(1) | 13.7 | 1093 | 12.7 | - |
| | HR + An(2) | 13.7 | 1093 | - | - |
| 8 | HR + An(1) | 27.4 | 980 | 11.9 | 70.6 |
| | HR + An(2) | 27.4 | 980 | 102.4 | 59.9 |
| 9 | HR + An(1) | 13.7 | 1093 | 20.2 | 64.0 |
| | HR + An(2) | 13.7 | 1093 | 18.5 | 82.5 |
| 9 | HR + An(1) | 27.4 | 980 | 17.9 | 75.3 |
| | HR + An(2) | 27.4 | 980 | 38.7 | 34.3 |
| 9 | HR + An(1) | 13.7 | 1093 | 18.3 | 137.2 |
| | HR + An(2) | 13.7 | 1093 | 34.7 | 38.0 |
| An(1) = 1038° C/1h/Air Cool | | | | | |
| An(2) = 1177° C/1h/Air Cool | | | | | |

TABLE IV

| Tensile Properties | | | | | |
|---|---------------|---------------|---------------|----------|-------------------------------|
| Room Temperature Tensile Data | | | | | |
| Hot Rolled at 1120 °C | | | | | |
| Alloy | Y.S. (MPa) | T.S. (MPa) | Elong: (%) | R.A. (%) | Hardness (R _a) |
| G | 841 | 993 | 31.0 | - | 27 |
| 1 | 807 | 979 | 31.0 | - | 30 |
| 2 | 841 | 1089 | 29.0 | - | 28 |
| 3 | 1041 | 1234 | 24.0 | - | 34 |
| H | 620 | 814 | 31.0 | - | 99 R _b |
| I | 804 | 1000 | 20.0 | 39.0 | 27 |
| 10 | 908 | 1143 | 27.0 | 62.0 | 30.5 |
| 11 | 909 | 1184 | 21.0 | 35.0 | 33.5 |
| Hot Rolled at 1120 °C plus Anneal (1040 °C/1h/AC) | | | | | |
| Alloy | Y.S. (MPa) | T.S. (MPa) | Elong (%) | R.A. (%) | Hardness (R _b) |
| G | 317 | 710 | 60.0 | - | 78 |
| 1 | 414 | 793 | 56.0 | - | 89 |
| 2 | 469 | 869 | 47.0 | - | 96 |
| 3 | 662 | 1082 | 38.0 | - | 29 R _b |
| H | 241 | 641 | 53.0 | - | 78 |
| I | 345 | 739 | 50.0 | 52.0 | 85 |
| 10 | 495 | 880 | 48.0 | 61.0 | 94 |
| 11 | 558 | 871 | 45.0 | 58.0 | 97.5 |
| Hot Rolled at 1120 °C plus Anneal (1040 °C/1h/AC plus) Age (750 °C/500 h/AC) | | | | | |
| Alloy | Y.S. (MPa) | T.S. (MPa) | Elong (%) | R.A.(%) | Hardness (R _b) |
| G | 483 | 903 | 37.0 | - | 97 |
| 1 | 531 | 972 | 34.0 | - | 99 |
| 2 | 586 | 993 | 35.0 | - | 23 R _b |
| 3 | 751 | 1158 | 26.0 | - | 32 R _b |
| H | 234 | 634 | 54.0 | - | 75 |
| I | 396 | 823 | 41.0 | 56.0 | 94 |
| 10 | 516 | 978 | 33.0 | 44.0 | 99.5 |
| 11 | 626 | 1229 | 19.2 | 32.0 | 24.5 R _b |

The data in TABLES II, IIA, IIB and Figs. 1 to 5 are illustrative of the improvement in sulphidation and oxidation resistance characteristics of the alloy composition within the invention, particularly in respect of those compositions containing over 3% aluminium and over 0.75% niobium.

Turning to Fig. 1, the low aluminium (less than 0.5%) alloys A to F reflect that their oxidation characteristics would not significantly extend the life of the 60 Ni - 30 Cr - 10 Fe alloy for the vitrification application given a failure mechanism due to oxidation. Cerium and cerium plus niobium did, however, improve this characteristic.

Similarly, Figs. 2 and 3 depict cyclic oxidation behaviour at 1100 °C and 1200 °C of Alloy I versus Alloys 10 and 11. The low aluminium, high-iron Alloy I fared rather poorly. The oxidation resistance of both Alloys 10 and 11 was much superior after 250 days than was Alloy I after, say, 50 days.

With regard to Figs. 4 and 5 and TABLE II, it will be noted that sulphidation resistance of the compositions within the invention was quite superior to that of the control alloy and of alloys beyond the scope of the invention. Alloys 3 to 9 were particularly effective (low iron, 3+ % aluminium and 1+ %

niobium). Alloy 5, based on all the test data, should have given a better result beyond the 40-day test period though it was many times superior to the 60 Ni - 30 Cr - 10 Fe control. (As in most experimental work involving corrosion testing and as the artisan will understand, there is usually, if not always, at least one (or more) alloy specimen which, often unexplainably, behaves differently from the others, in this case a composition such as Alloy 10. It is being reexamined).

With regard to the stress rupture results depicted in TABLE III, it will be observed that all the compositions within the invention exceeded the desired minimum stress rupture life of 200 hours at the 980° C temperature/13.7 MPa test condition, this in the annealed as well as the aged condition. The 60 Ni - 30 Cr - 10 Fe control failed to achieve the 200-hour level in the annealed condition. Referring to TABLE III-A and using Alloy 8 as a comparison base (approximately 30% Cr, 3% Al, less than 5% Fe and 1% Nb) it can be seen that the other alloys did not reach a combined stress rupture life of circa 100 hours and a ductility of 60% with the aid of a higher annealing temperature. The rupture life of Alloy 5, for example, was improved with the 1177° C anneal but ductility markedly dropped. It is deemed that the high chromium content contributed to this. The higher niobium of Alloy 9 is considered to have had a similar effect. As previously stated, it is with advantage that the chromium and niobium should not exceed 32% and 1.5% respectively.

Concerning the tensile properties reported in TABLE IV all the alloys within the invention, i.e. Alloys 1 to 4 and 11 to 13, compared more than favourably with Alloy H, an alloy similar to 60 Ni - 30 Cr - 10 Fe, irrespective of the processing employed, i.e. whether in the hot-rolled or annealed or aged condition. It is worthy of note that Alloys 1 and 11 were also tested for their ability to absorb impact energy (toughness) using the standard Charpy V-notch impact test. These alloys were tested at room temperature in the given annealed condition and the average (duplicate specimens) for Alloys 1 and 11 was 171 kgm/cm² and 120 kgm/cm² respectively. In the aged condition Alloy 11 exhibited a toughness of but 7.8 kgm/cm². This is deemed to result from the higher aluminium content. In the aged condition Alloy 1 had 137 kgm/cm² impact energy level.

While the present invention has been described with reference to specific embodiments, it is to be understood that modifications and variations may be resorted to without departing from the spirit and scope of the invention, as those skilled in the art will readily understand. Such modifications and variations are considered to be within the purview and scope of the invention and appended claims. A given percentage range for an element can be used with a given range for the other constituents. The term "balance" or "balance essentially" used in referring to the nickel content of the alloy does not exclude the presence of other elements in amounts which do not adversely affect the basic characteristics of the invention alloy. It is considered that, in addition to the wrought form, the invention alloy can be used in the cast condition and powder metallurgical processing can be utilised.

Claims

1. An alloy consisting essentially, by weight, of 25 to 35% chromium, 2 to 5% aluminium, about 2.5 to 8% iron, up to 2.5% niobium, up to 0.1% carbon, up to 0.05% nitrogen, up to 1% titanium, up to 1% zirconium, up to 0.01% boron, up to 0.05% cerium, up to 0.05% yttrium, up to 1% silicon, up to 1% manganese, balance nickel.
2. An alloy according to claim 1 containing 2.5 to 4% aluminium, 2.5 to 5.5% iron, 0.75 to 1.5% niobium, up to 0.05% carbon, up to 0.012% cerium, up to 0.5% titanium and up to 0.5% zirconium.
3. An alloy according to claim 1 or claim 2 in which the chromium content is at least 27%, the aluminium content is at least about 2.5% and the niobium content is at least about 0.5%.
4. An alloy according to any preceding claim in which the chromium content does not exceed 32%, the aluminium content is from 2.75 to about 4%, the iron content is from 2.75 to about 5% and the carbon content does not exceed about 0.04%.
5. An alloy according to claim 3 or claim 4 in which the niobium content is from about 0.75 to 1.5%.
6. An alloy according to any preceding claim which contains about 0.005 to 0.015% cerium.
7. An alloy according to any preceding claim in which one or both of titanium and zirconium is present in an amount up to 0.5%.
8. An alloy according to any preceding claim in which manganese is present in a content up to not more than 0.5%.
9. An alloy according to any preceding claim in which the silicon content does not exceed 0.5%.
10. An alloy according to any preceding claim in which nitrogen is present in an amount up to 0.05%.
11. An alloy according to claim 10 in which the nitrogen content does not exceed 0.04%.

12. The use of an alloy according to any preceding claim for glass vitrification furnace parts.

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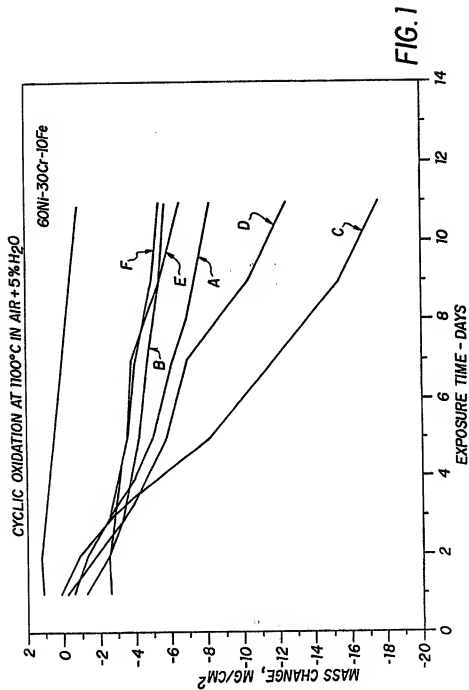
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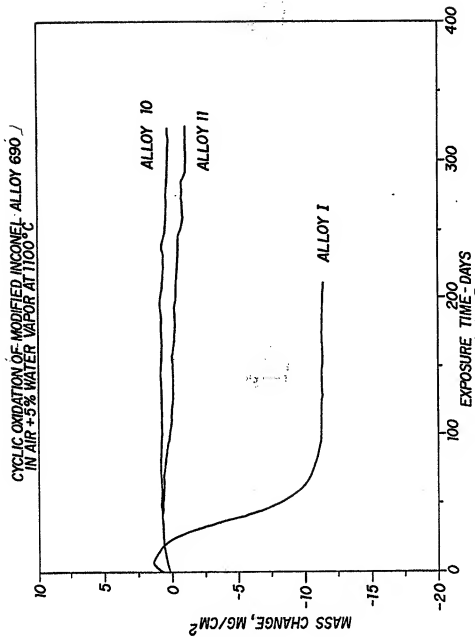


FIG. 2

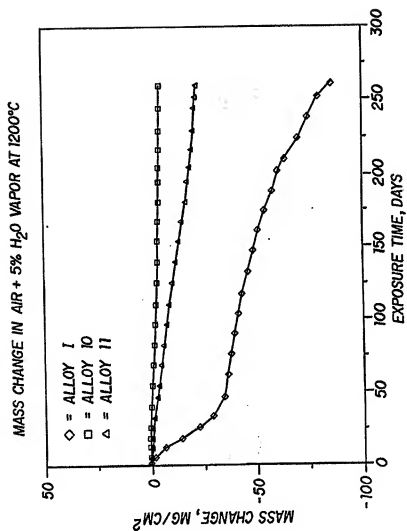


FIG. 3

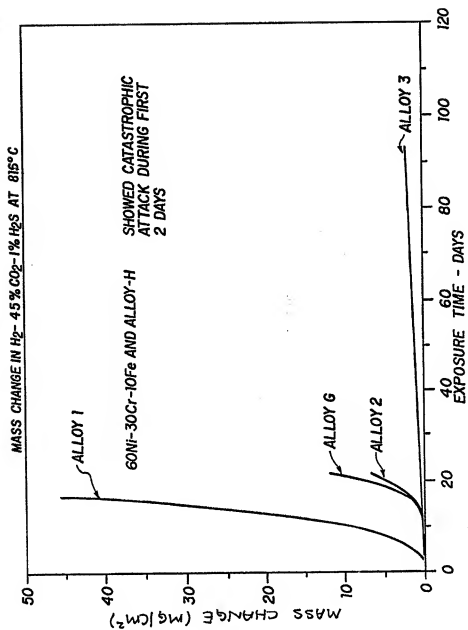


FIG. 4

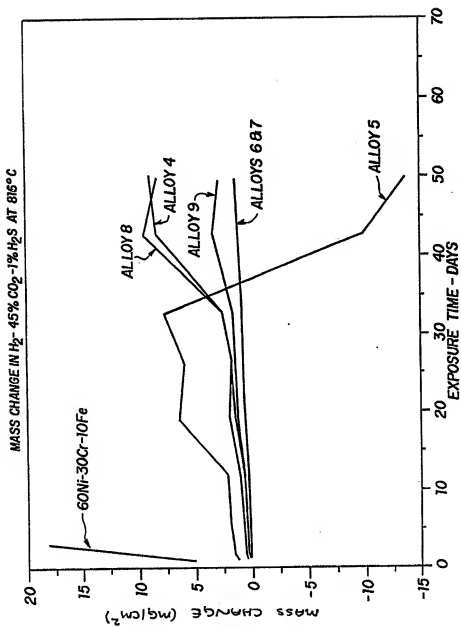


FIG. 5



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-Application Number

EP 89 10 7207

| DOCUMENTS CONSIDERED TO BE RELEVANT | | | |
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| Category | Citation of document with indication, where appropriate, of relevant passages | Relevant to claim | CLASSIFICATION OF THE APPLICATION (Int. Cl. 4) |
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| X | EP-A-0 261 880 (INCO ALLOYS INTERNATIONAL INC.) * Page 5, lines 52-54; table 2 * | 1,4,7-9 | |
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| The present search report has been drawn up for all claims | | | |
| Place of search THE HAGUE | | Date of completion of the search 10-07-1989 | Examiner GREGG N.R. |
| CATEGORY OF CITED DOCUMENTS | | T: theory or principle underlying the invention E: earlier patent document, but published on, or after the filing date D: document cited in the application L: document cited for other reasons | |
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